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The Case For Smartphones As An Urgent Computing Client Platform

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Abstract

The computing world is now populated with smartphones which combine the features of a phone with a general purpose computer and come loaded with sensors including digital cameras, global positioning system (GPS) receivers, accelerometers and many more. In this paper we argue that these devices are an ideal platform for collecting data for use in urgent computing simulations. We describe how these devices will have far reaching impacts on how people connect with and organize their communities and discuss how this coincides with the rise of community driven response to disasters and the need for decentralized command and control that is discussed in disaster management literature. We also that smartphones, by providing technology which can network people without the use of centralized infrastructure, and which are carried, used, and maintained as part of daily life, are a promising platform for building distributed disaster management applications, which could be part of the inputs provided to an urgent computing simulation. In this paper we describe not only the potential of the platform, but also analyze the challenges it faces in order to realize that potential, and discuss how our middleware is designed to meet these challenges and bring about the future of disaster management applications for smartphones using urgent computing.

Keywords:
urgent computing, smartphone, mobile, disaster management

Introduction

There are new mobile devices today, commonly called smartphones, that combine features from a cell phone a general purpose computer and a digital camera into one package which people can easily carry around. In addition, such devices allow users to install new applications not bundled with the device by the manufacturer. The advanced feature sets available on these devices and the ability to install new applications, combined with the inherent mobility they provide is radically altering the places and ways that we use computers. These devices have the ability to communicate using a variety of networks, from bluetooth to wireless Internet (Wi-Fi) and increasingly fast cellular networks including 3 and 4G services. This is combined with features like: on board global positioning systems (GPS); still and video cameras; other advanced sensors for temperature, pressure, acceleration; an increasingly large screen; as well as general purpose computing hardware. Smartphones are quickly becoming ubiquitous much as cell phones are today[1] and there are many novel applications being developed which take advantage of the unique features not available on traditional cell phones which only provide call and SMS features.

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The rise of these new devices coincides with a shift in the consensus approach to disaster management. Increasingly disaster management scientists have realized that normal citizens are critical to effective disaster response[2, 3], particularly as the size of the disaster increases. In such situations it has been demonstrated that centralized command and control structures can not provide the flexibility to handle the organizational challenges posed by disaster situations[4, 5, 6]. These challenges can not be addressed by military style hierarchical decision making. This is because such organization does not offer the agility to handle the ad-hoc organizations which emerge spontaneously in response to a disaster. This is particularly true in the case of larger scale events. Furthermore, it has been shown that smaller self managed organizations are more productive than more traditional management structures[7]. What is therefore required is new technology with the ability to network people and act as a platform for emergent behaviors during a disaster response.

Such a platform must also be able to take advantage of large scale computation and simulations provided by a centralized cloud platform when urgently needed. Such a usage we considered to be an example of "Urgent Computing", which we define as computations involving high performance resources which have a real world deadline, which if not met may have significant negative consequences. We envision applications, such as climate or evacuation modeling, or realtime video processing, where the sensors found on these devices, along with data gathered in the field by smartphone users are used to drive modeling simulations being run on cloud based high performance computing resources. The results produced by such a simulation would then be distributed back to the smartphones of users in the field, aiding them in decision making. For instance, a short video clip of the occupants of a stadium in need of evacuation could be analyzed in the cloud in order to estimate the size and distribution of the crowd and the results of that analysis fed to an evacuation simulation. The results of such a simulation could then be returned to the smartphones of coordinators on the ground to speed the evacuation.

We argue that the combination of features found on smartphones are an excellent platform for just such a system and outline our research to enable and accelerate the emerging utility offered by the smartphone platform as an urgent computing client platform. We begin by discussing the unique aspects of smartphones in more detail in order to characterize the promises the platform offers for urgent computing for disaster management in particular. Next we discuss the rise in the importance of distributed citizen response and its implications on organizational structures, not only during disasters but across society as well. We then argue that the features offered by smartphones are uniquely suited to meet the challenges demanded by citizen response to disasters. We next explain how our research focuses on enable these new applications by enabling data oriented applications to synchronize in distributed, ad-hoc networks, and provide input as well as launch modeling and simulation using cloud based urgent computing platforms. We evaluate this software framework from the perspective of some distributed data gathering applications and show that we have already achieved some of our goals of enabling smartphones as a client platform for urgent computing applications.

Promise and Challenges

We begin by describing the promise and challenges the smartphone platform faces when considering it for use as an urgent computing client platform. There are several critical features of the emerging smartphone platform that are vital to their utility; chief among these are mobility, location awareness and connectivity. The near ubiquity of cell phones in the western world is largely driven by the connectivity that the cellular networks offer and their ability to connect people as they move about in the world. As Arnold points out, "even if the phone is never used, it can be carried at all times, and the very fact that it is possible to communicate, of itself creates a link that reinforces connectedness[8]." This mobile connectivity offers a unique utility and when bundled with more advanced features provides a strong force for smartphones in the market. They are thus expected to become nearly ubiquitous and to provide extremely high utility[1].

Cell phones have already been observed to be of high utility in disaster situations where they are used "to interact, negotiate and establish the initial network of professionals in order to meet the threats posed by a major incident[9]." This is in no small part due to the fact that "a mobile phone number provides the only fixed address to otherwise flexible, independent and mobile individuals[8]". Thus, in addition to the connectivity that the cell phone offers it also offers a fixed address. This provides diverse utility; from community to family life, from daily business to a crisis scenario, the combination of address and communication helps organize and connect together individuals and diverse groups. It has also been observed that "the timely spread of reliable information is a vital part of the response to and recovery from a disaster.[10]" and mobile devices play a key role in this process.

The trouble with relying on cellular networks however is that they have centralized points of failure in the form of cell towers, which can be easily rendered inoperable in a disaster, in addition to having limited capacity[11, 12], and thus communication is often lost or overloaded on these networks[13, 10] in the face of a major disaster, particularly in the face of many people in the disaster area attempting to make calls for help. Despite these problems, in the case of hurricane Katrina[13] it was seen that cellular phones were the first communication technology that became operational in the aftermath[14, 12, 10]. Thus, the technology from which smartphones are evolving has already shown utility in various crisis situations and the importance of this communication medium can not be stressed enough. What is needed is a way to eliminate the requirement on centralized communication facilities, such as cell towers, in order to provide the robust utility demanded by disaster response. It has been argued that, "Mobile systems can only succeed if devices are able to communicate in a dynamic and flexible way[6]," and that "Crises involve the necessity for many hundreds of individuals from different organizations to be able to freely exchange information, delegate authority, and conduct oversight"[15], and smartphones are uniquely positioned to be a flexible communication tool which can facilitate such exchanges provided the challenge of failed communication networks can be overcome.

The promise of smartphones is that they are built with multiple networking technologies. A typical device contains Bluetooth networking technology for short range communication, Wi-Fi based networks for longer range communication, in addition to the traditional, centralized cell phone networks for even longer range communication. Considerable research is being done to use wireless ad-hoc networks to replace lost infrastructure[16, 17, 18] such as cell towers. Already devices shipped today are able to create mobile ad-hoc "hotspots" to connect together multiple phones. In addition, so called "Mobile Ad-Hoc Networks" (MANETS) composed of only mobile devices, such as smartphones, are networks which operate by sending data packets in a hop-by-hop fashion between phones. This exchange of data can be leveraged not only to send text messages but even to provide voice-over-IP services similar to how Skype operates on the Internet. Even better, if the data is of utility to all users in the network then the hop by hop can be seen as a form of distributed synchronization which can run over multiple networking technologies and take advantage of the mobility of the users using the system to ferry data between isolated islands of network connectivity. The data can be exchanged over bluetooth or over ad-hoc WiFi when cellular connectivity is not around.

Fortunately, WiFi networks are being integrated into existing wireless Internet infrastructure and cellular networks to provide the kind of communication flexibility that is demanded in a crisis situation[19]. Projects like Serval[18] have already shown that it is possible to provide mesh internet and telephony services using only mobile phones. Bluetooth connectivity offers yet another form of communication that could be exploited to provide connectivity in situations where other networks have failed. Our work is aimed at providing users with the ability to create structured data stores and synchronize those data stores, without the need for centralized resource, as well as to launch and utilize cloud resources to offload computation intensive calculations from the phone. The combination of these features creates a platform for urgent computing, where data collected using a smartphone can be synchronized to cloud resources for computationally intensive cloud processing, when networking resources allow. Through this work, we argue that the smartphone is ideally suited to disaster scenarios due to the ability to use various communication mediums to overcome loss of centralized communication resources upon which users normally rely. The robust communication facilities which are possible on smartphones combined with the expected ubiquity[1] makes them extremely compelling devices for further research.

This ubiquitous distribution is another important factor in the promise of the smartphones as a platform. It has been argued that, "Above all, the emergency communication tools for the general public must be affordable, available, and applicable during their day-to-day life in order to ensure that they will be used during a crisis [20]". The smartphone is an ideal communication tool in this respect because owners of such devices are likely to use them every day to communicate with their existing organizational structures such as work colleagues, friends and family. In an emergency situation individuals are very likely to leave other computing devices, such as a desktop and even laptop computers, behind as they flee. However, the small size and ability to enable communication offered by smartphones make them highly likely to be carried around constantly by people. Many cell phone owners have a near unconscious habit of ensuring they have their phone with them at all times so that they are sure to be connected with friends, family and colleagues as they move about.

The fact that people are willing to carry a smartphone around all the time, and are likely to purchase one for themselves, is also ideal for disaster organizations since they are often faced with "resource constraints that inhibit the purchasing or upgrading of equipment and paying for training costs (which can be prohibitive) to learn new technologies not used on a regular basis[20]." Because the smartphone has utility outside of disaster management contexts it is likely that they will be maintained and upgraded by individuals within an organization often with their own money. Furthermore, it has been observed that, "An emergency system that is not used on a regular basis before an emergency will never be of use in an actual emergency[15]." Thus, it is vital that applications have common utility so that they are used on a regular basis and thus can be used when disaster strikes, but even more essential that users be able to install such applications; something which is simply not possible on traditional feature phones.

Furthermore, because they are commodity devices the costs are expected to be much lower than specialized hardware could ever be and are likely to be properly maintained by the owner due to the daily utility of the device. What is needed, therefore, are applications that have daily utility so that users will learn how to use them in the course of their normal life, and thus will have the skills required to operate the applications in the event of a disaster. Note however that there are a number of different smartphone platforms which are available today and that compatibility between these platforms is not good. Standards need to be made, similar to how web standards have allowed the web to flourish despite multiple browsers, in order to enable the development of cross platform applications. This is vital to enabling the shift in disaster response from that of a centralized official response to that of a distributed citizen response often discussed in the literature. However, the communication and daily utility of smartphones isn't the only feature of high utility in a disaster, battery life is also an important factor.

While smartphones operate on limited batteries, they have lifetimes that are considerably longer than the average laptop. The average phone can last for a day or two in standby and can talk for several hours. This offers computation and communication resources that can last much longer when a disaster strikes than similar mobile resources such as a laptop which has a lifetime on the order of just a few hours. Furthermore, there are already hand-crank phone chargers on the market that can easily be used to provide additional power for these devices when disaster strikes as well as solar panels for charging during daylight hours. For larger resources like a laptop a generator or significantly larger solar panels are required. The better battery life of smartphones allows features like the GPS in the device to be used for a prolonged period of time while providing a higher level of portability than similar technologies. Still, power consumption is a very hard problem for all disaster related technology, and considerable work needs to be done to reduce power consumption of such devices as well as scavenging energy[21] from the environment via heat, motion or wireless sources.

The presence of a GPS and other location technology in smartphones is also extremely valuable in a disaster situation for various reasons, including the fact that it may provide a good way to help filter incoming information[22]. Location information is invaluable to those who join the response but do not have personal knowledge of the disaster area[12]. By encoding information with geographic data it becomes easier to visualize the data and can be used for better situational awareness, even when the data is provided from multiple sources[23]. This information is of high utility to responding organizations. Smartphones offer a unique platform for collection of geographic information including photos, videos and individual responder locations. The utility of location information is not limited just to a disaster though. Such information also is of high utility in every day life both in terms of mapping but also in terms of finding information related to location.

In conclusion, we have argued that the smartphone poses a unique potential to be an excellent client platform for urgent computing. The availability of multiple on board sensors, especially that of location, the ability to access multiple networks as well as set up ad-hoc networking infrastructure, the near ubiquity of the platform, and significantly longer battery life than similar devices make the smartphone an excellent candidate for a client device for urgent computing. We next address the issue of community driven response in a disaster area, which we feel is a significant trend in the disaster management community, and poses a unique challenge for smartphones as an urgent computing client.

Distributed Community Driven Response

When a large scale disaster strikes the initial response is almost exclusively by untrained or semi-trained individuals who just happen to be in the wrong location at the wrong time.

> "Logically, the proportion of semi-trained and untrained responders increases with the scale of event, and they assume greater responsibility for response activities. In catastrophes, they may handle local

responses entirely, with experienced responders not arriving until the recovery phase[24]."

Thus it is vital to an effective response to have communication facilities in place to support the activities of these individuals as they come together in emergent, temporary organizations that improvise rescue and relief efforts[25]. The smartphone platform is well suited to aid individuals in such cases because it can be made to support robust communication facilities and will be already on hand when disaster strikes.

Through the use of smartphones to communicate situation specific information, provide discovery of others participating in the response, as well as assist in community organization, the platform becomes technology which "not only changes how we communicate it changes how we structure our communities[8]." This change is also reflected in some of the disaster management literature which is shying away from top-down military style command and control structures and embracing more organic structures, in part because of the agility required for successful response to complex emergencies[4] but also because of the emergence of citizen based ephemeral disaster response groups which require collaboration, cooperation and transparency, values which do not fit well with a top-down structure of command and control[26]. Part of this change is due to the advent of cell phones which have provided new ways for groups to communicate and coordinate and smartphones are a natural extension that will further drive these changes.

In the case of a disaster, emerging organizations often don't have an existing organizational structure to work with and so what is needed is a form of cooperative activity that can benefit from new technology to help mediate the interactions between new and existing groups[25]. Thus, there is a need for technology which can support ad-hoc organization and which can help to assist an adaptive self organized response by individuals and groups that coordinate an effective response effort in a decentralized fashion[20, 5]. Parallels can easily be seen with self organizing swarm systems, such as ants or so called swarm-bots, where very simple behaviors at the individual level can be turned into what appears to be an organized group ballet[27, 28]. Systems organized in these ways are able to avoid problems with wrong information at the global level leading to wrong decisions and dependence on the decision makers at the highest level, a single point of failure. Instead distributed decision making organizations can provide the flexibility and autonomy required at the local level to form an effective response[29, 30].

The promise of the smartphone platform is that it is a ready made device that could be used to provide the level of coordination and information sharing that is required to organize these groups and that they can do so not just during a disaster but in all aspects of modern societies. This is because "society is both prior to technology, and emerges from technology[8]". Society has reorganized to some degree already due to the cell phone and the cell phone is growing into the smartphone in part because of this reorganization. In order for smartphones to have the highest utility during a disaster it is important that they have utility outside of a disaster to avoid the issues with training users to use the system and ensuring proper maintenance. Thus there is a need to drive the smartphone platform as a community network as much as there is a need to change how communities network themselves. Our software, which enables structured data gathering and synchronization, partially fills this need. However, the challenge for the smartphone as an urgent computing client is that average users will not know how to take advantage of urgent computing resources to process the collected data. Additional work is needed to develop applications and system which can perform interesting and understandable tasks using urgent computing resources which will be accessible to the larger community.

The Impacts of Social Networking

We would be remiss in our discussion of community driven response if we did not address the rise of social networking. Recently the Internet has seen the rise of large social networking oriented sites such as Facebook, Twitter, MySpace, LinkedIn, Orkut and many others. These sites offer compelling platforms for applications because they connect users with one another in new ways. They allow users to effectively create virtual communities with which they can share information. Increasingly such networks are open to external development via various APIs and applications on these platforms continue to grow. It has already been observed[31] that the socially convergent behavior seen in the physical world is mirrored in on-line communities and technology needs to be developed which reflects and supports these behaviors.

"All response technology should actively nurture cooperation, collaboration and partnership formation[24]." Smartphones are a good platform for building citizen based response applications which help people to organize their response efforts much as Internet based social networking sites allow citizens to organize today. The communication facilities available on this platform make it easy to build informal, ad-hoc channels of communication for coordination of response efforts that is needed when disaster strikes[26]. The important thing to realize is that these facilities can and should be based on existing community networks that are in place before a disaster strikes as well as facilitate the emergence of new organizational structures.

The Internet has in many ways redefined what a community can be and smartphones are poised to do the same on a massive scale due to the mobility of the platform. Thanks to technologies like smartphones people will no longer need to be physically close to coordinate and discover each other[25] and thus create new virtual organizations. Instead they can rely on the platform to assist them in networking their community together and in turning their existing community networks into effective disaster response organizations. Work is needed to make such applications able to function in the face of loss of centralized components but the applications already exist and have shown their popularity and utility. It isn't so much a question of will community networks be built but more a question of how can they be leveraged during a disaster to make an effective response. Given that it is clear that a substantial number of diverse organizations, including ephemeral ad-hoc organizations, are likely to be active in the various phases of emergency response[26], the question becomes how to leverage the users connections with other people in the most effective way possible when disaster strikes.

In conclusion, by combining the power of social networks with mobile devices like smartphones new applications which allow citizens to help each other to overcome the challenges posed by a disaster will emerge and revolutionize disaster management. Work is needed to overcome the challenges the disaster poses in terms of loss of connectivity to allow social networking applications to continue to operate in the face of loss of centralized components on which all of the existing social networking systems rely. Further work is also needed to create applications which are enabled to allow users to assist in disaster response, particularly with respect to urgent computing related tasks. We address this challenge in the next section.

Enabling Applications for Disaster Response

Our research in this area focuses on the low level requirements of applications for new social enabled networking applications we envision. We have built a distributed data management system on which application developers can easily create the kinds of applications that are needed to enable the smartphone platform to work effectively both in a broader societal context but also during a specific crisis event. This system focuses on applications associated with gathering, sharing and managing structured data. This may include photos and videos, location and other sensor data, as well as any other data the user feels is important to collect. Our system enables users to define a structured data store on their phone, enter data into that data store and then share that data with others over ad-hoc networking channels such as "Hotspot" mode found on many modern smartphones, as well as via cellular data networks when available. We this system will enable a host of new data oriented applications appropriate for disaster management. In conjunction with our Cuckoo framework for offloading computation we have created a platform which could easily be leveraged for urgent computing applications driven by the smartphone client.

Cuckoo

Cuckoo is a computational offloading framework which makes it easier for application designers to write programs which can be partly run in the cloud. In order to support proper operation when network resources are unavailable, as might be the case in a disaster, Cuckoo supports the bundling of both a local phone implementation, as well as a cloud enabled version of a particular computation. Bundled with Cuckoo is a resource manager which allows the user to setup offloading resources, such as a private home server, or a cloud resource. The user supplies this application with the necessary configuration information and credentials to access the cloud resource.

An application which uses Cuckoo for computation offloading, can then load its computation to any resource running a Java Virtual machine, either being machines in a commercial cloud such as Amazon EC2 or private mini clouds such as laptops, desktops, home servers or local clusters. The user runs a simple Java application, the server, on such a resource to enable it to be used for computation offloading. The server that runs on such a resource does nothing by itself, however, services available on a phone can be installed onto such a server. Cuckoo then makes a decision based on the available resources to either offload the computation to the cloud or attempt to run it on a phone.

If required Cuckoo can launch a cloud computing resource, such as an Amazon EC2 virtual machine instance, install the service on the server and then launch the processing of gathered data in the cloud. Alternatively Cuckoo can use the local phone implementation if network services are unavailable. In this way, Cuckoo can be robust in the face of a network failure. The features of Cuckoo may be well suited for urgent computing applications, where a user may need to run a particularly large calculation for a particular application but only has access to a new resource they have never seen before due to the nature of the disaster. Because Cuckoo always bundles the server implementation on the phone it is a simple matter of installing a very simple, generic Java server on the new resource and running it in order to allow the phone to take advantage of this resource. It is easy to imagine installing the server jar on a laptop in the field and then offloading complex computations from the phone to the laptop.

While we feel that this system is ideal for urgent computing from a client perspective, further work is needed to address the delay of provisioning of machine instances on cloud platforms, or giving users access to already provisioned resources when their needs are urgent due to a disaster situation.

RAVEN: Versioned Databases

Our research has led us to identify a number of applications for disaster management that would be of high utility in a disaster situation. Examples include bus management for the evacuation of the Superdome during hurricane Katrina, tracking lost and found people effected by a disaster, and even collecting trusted images and video of the situation on the ground. What we have found is that each of these applications require a structured data store for sharing information, and thus we have built a software system, called RAVEN, capable of creating arbitrary structured data stores on Android powered smartphones, entering data in these data stores, and versioning them in order to enable arbitrary sharing of data with other users over ad-hoc networks as well as synchronize the data with cloud resources.

As a portion of the evaluation of what our system is capable of we have implemented a 'People Finder" application consists of a user interface for editing records in a database which can be used to track lost and found people. This application can take advantage of advanced on device features by including the users location, and a photo of the person along with the collected data. The implementation of this application using RAVEN was undertaken entirely on the phone. Using our "Schema Creator" application bundled with the framework we constructed our People Finder application. The resulting schema was then installed in the system as a new data type. The user interface for this version of the application was then generated based solely on the schema for the application by RAVEN. Users of the application can share the complete application with others simply by synchronizing the data over an ad-hoc WiFi network or 3G.

Using this evaluation application we have demonstrated that our system provides application developers and users with the ability to easily create collaborative editing applications which use structured data stores. The generic interface engine which can generate an edit user interface for such data at runtime, allowing our system to support dynamic schemas for structured data stores, with editing and storage on mobile devices.

Our system is built for Android powered smartphones. Android is a good platform for our work since it is an open system which is rapidly gaining market share. We value openness because it allows us to conduct our research in the most efficient way possible and to easily publish our results without restriction. There are no technical reasons why our work can not be ported to other platforms but is an engineering challenge which is out of scope for our research.

RAVEN: Design

Our system consists of four layers as illustrated in Figure 1. At the bottom of the stack is the Versioning layer which gives us the features needed to track versions of the database and share those versions with other users. This layer is composed of a Git repository. Git is a distributed version control system initially designed and developed by Linus Torvalds for Linux kernel development. In Git every working copy is a full-fledged repository with complete history and full revision tracking capability which is not dependent on network access or a central server. This is ideal for working in a frequently partitioned networking environment common in disaster situations, since it tracks the complete Directed Acyclic Graph of versions. Git forms the basis of the versioning and sharing layer. It provides us not only with features for tracking versions and branches, but also with synchronizing with other users or centralized repositories of data via the Git push and pull protocols.

Above this layer is the database layer, which gives us the raw data storage features of the system. For this layer we use an SQLite database, which is an embedded relational database system ideal for smartphones. It is unusual in that it uses a dynamically and weakly-typed which we use in our system to enable a more compact on disk encoding for the data stored in the system. On top of this database layer we make use of Android's database abstraction layer called Content Providers.

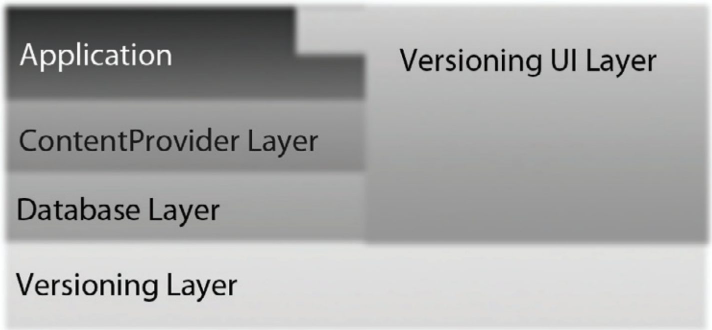

Figure 1: Design of the Interdroid Versioned Database system. System components are written with black text.

Content Providers can be used to store and retrieve data across applications and provide a row oriented abstraction of databases to applications. They are the suggested way to share data between applications on the Android platform. How a content provider actually stores its data is up to the author of the datastore. However, all content providers implement a common interface for querying the provider and returning results, as well as for adding, altering, and deleting data within a given provider. Most common is the use of an SQLite database just as we use in our system. The data model exposed by content providers is a table based model and queries return a Cursor object which can be used to move through the table of results and extract data. Content providers expose their data through a series of public identifiers, called Uniform Resource Identifiers (URIs), that uniquely identify the data in question on the entire device.

Our system supports the use of the Apache Avro[32] schemas to construct a new Content Provider and underlying SQLite data store at runtime. The system also provides an edit interface for records within this database which is also generated at runtime based only on the Avro schema written by the user. As an example of using this system we present screen-shots of a simple "To Do" application. We show two versions of this interface before and after a due date is added to the schema for the application in order to demonstrate that the user interface is easily able to adapt to the new schema.

Once a database is instantiated, records may be entered and synchronized with other users of the system.

Related and Future Work

A great deal of work has been done on both synchronization and collaborative editing on mobile devices. In this section we give a far from exhaustive overview of some of the most similar systems to ours, due to space constraints.

In Syxaw[33] the authors give a general synchronization system for extensible markup language (XML) oriented documents. This system differs from ours in that we focus on structured data stores which are natural to query, while they focus on document oriented system with an emphasis on XML.

The same is true for DocX2Go[34] which makes use of optimistic replication just as our system does, and can work in a fully decentralized way. However, the XML focus of the platform makes it inappropriate for many applications. Furthermore, they do not focus on the user interface components required to enable editing of structured data.

In the Disco[35] framework the authors explore how applications can handle operation of collaborative systems in the face of disconnections. This system focuses more on handling disconnection in synchronous systems and not on data representations and user interfaces, while we assume asynchronous operations and focus on schema and user interface issues.

While the system is already very promising there are a number of issues remaining to be addressed before we have reached our full vision. First and foremost we need to create a merge user interface that can be used to merge separate forks in the causality tree into a single database. In the face of concurrent operations it is likely that users will make conflicting writes to the database. We have already begun preliminary work on this providing queries to do a three way merge of the data in two databases within our system. Using the Avro User Interface components we have already built we will help the user to easily resolve conflicts within the system. As an additional improvement we would also like to improve the types of widgets that we support as a native portion of application creation so that users can easily create applications with more expressive user interfaces.

Recently there have also been a number of applications for smartphones targeted specifically at emergency response. The most famous of these is the "Fire Department" app from the San Ramon Valley Fire Protection District. This application provides users with information about recent emergency events on a map. It also can be used to find the location of an automated defibrillator. This application requires that the phone be connected to the internet in order to operate properly. Such an application could be rebuilt using our approach relatively easily allowing users to share data on recent events in an ad-hoc fashion.

Conclusions

The features available on new smartphone devices offer a unique combination of mobile computation, location information, ability to install custom software, and connectivity that has never before been seen. The combination of these features offers great promise for society in general and disaster management in particular. The rise of Internet based social networking sites shows the value of connectivity but work is needed to make the value of these kinds of systems available when disaster strikes and centralized components and connectivity are lost. There is a need to build systems which can operate offline as well as use the variety of networking technologies available on these new devices in order to enable hop by hop communication when centralized networking infrastructure fails. By leveraging the networking features of these devices properly, through avoidance of centralized components, it is possible to make the power of these devices available when disaster strikes. This will not only change the utility of the devices themselves but will change the way organizations are formed, structure command and control, and communicate. We anticipate that this will have far reaching effects, not only for disaster management, but on society at large. However, there are significant policy issues which must also be addressed for this vision to become a reality and additional research is required on how to integrate such technology into more traditional organizations which respond to disasters. With our evaluation we have shown that we have enabled users to create appropriate disaster management applications when a disaster strikes and to allow users to exchange collected data in arbitrary patterns.

Furthermore, we have argued that smartphones make a good client platform for disaster management systems using urgent computing. By virtue of the fact that users are likely to carry and maintain these devices they are likely to be available when disaster strikes. Applications which allow users to network with others before and during a disaster will be critical to future disaster responses. However, work is needed to enable these applications to function properly when disaster strikes. We have detailed our work in this area aimed at enabling data oriented applications which can share their data over arbitrary networking technologies, and can handle the changing structure of data collection in the field. We that this system will be of value during a disaster precisely because it has utility in daily life but is easily re-purposed to needs in a disaster. Finally, while we feel that this platform can be a good client platform for urgent computing workloads, further work is needed to define applications which can take advantage of these resources from a smartphone. Our work on Cuckoo has many of the desirable client features but work is needed on applications which can take advantage of these feature.

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